A study of the nuclear medium influence on neutral strange particle production in deep inelastic neutrino scattering

SKAT Collaboration

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Abstract

The influence of nuclear effects on the production of neutral strange particles (V°) is investigated using the data obtained with SKAT propane-freon bubble chamber irradiated in the neutrino beam (with E_ν = 3-30 GeV) at Serpukhov accelerator. The measured mean multiplicity of V° particles in nuclear interactions, $< n_{V^\circ} >_A$ = 0.096±0.011, is found to exceed significantly that in 'quasinucleon' interactions, $< n_{V^\circ} >_N$ = 0.059±0.012. The ratio of $\rho_{V^\circ} =< n_{V^\circ} >_A / < n_{V^\circ} >_N$ =1.61±0.23 is larger than that for π^- mesons, ρ_{π^-} = 1.10±0.03. It is shown that a dominant part of the multiplicity gain of V° particles can be explained by intranuclear interactions of produced pions.

1 Introduction

The experimental study of inclusive spectra of charged hadrons produced in the lepton-nucleus deep inelastic scattering (DIS) exhibits a significant influence of the nuclear medium on the particle yield in various phase space regions (see [1, 2] and references therein). The secondary intranuclear interactions results in a depletion of the fast hadron yield (in the current quark fragmentation region) and, to a more extent, an enhancement in the target fragmentation region. The magnitude of these effects and its dependence on the energy ν transferred to the hadronic system or on its invariant mass W are found [1, 2, 3] to be in qualitative agreement with prediction of models [4, 5] considering the space-time evolution of the quark string fragmentation and the hadron formation in the nuclear medium.
The magnitude of the nuclear effects on the particle yield can differ for various types of hadrons, for example, for charged ones (predominantly pions) and for the neutral strange particles (V°). Indeed, the yield of the latter in 'elementary' lN interactions is more than one order of magnitude lower than for the former (c.f., for example, the data [6, 7, 8, 9] on νN interactions). Hence, the secondary intranuclear reactions $\pi N \rightarrow K^\circ X$ and $\pi N \rightarrow \Lambda^\circ X$, though their relatively small inclusive cross sections, can cause a large gain of the V° yield in the target fragmentation region. On the other hand, the depletion of the V° yield in the current quark fragmentation region is expected to be weaker due to the smaller absorption cross section of strange particles as compared to that for pions.
Hitherto these expectations for the leptoproduction of strange particles on nuclei are not checked experimentally. This work is devoted to study of nuclear effects on the neutral strange particle production in the neutrino-nucleus DIS at intermediate energies, ν = 2-15 GeV and W = 2-5 GeV. In Section 2, the experimental procedure is briefly described. The experimental results are presented and discussed in Section 3. The results are summarized in Section 4.

2 Experimental procedure

The experiment was performed with SKAT bubble chamber [10], exposed to a wideband neutrino beam obtained with a 70 GeV primary protons from the Serpukhov accelerator. The chamber was filled with a propan-freon mixture containing 87 vol% propane (C_3H_8) and 13 vol% freon (CF_3Br) with the percentage of nuclei H:C:F:Br = 67.9:26.8:4.0:1.3 %. A 20 kG uniform magnetic field was provided within the operating chamber volume. The selection criteria of the properly reconstructed charged current interactions and the procedure of the reconstruction of the neutrino energy E_ν can be found in our previous publications ([1] and references therein). Each event was given a weight (depending on the charged particle multiplicity) which corrects for the fraction of events excluded due to improperly reconstruction. The events with $3 < E_\nu < 30$ GeV were accepted, provided that $W > 2$ GeV and the transfer momentum squared $Q^2 > 1$ (GeV/c)^2. The number of accepted events was 3101 events (3706 weighted events). The mean values of the kinematical variables are: $< E_\nu > =$ 12.2 GeV, $< Q^2 > = 3.6$ (GeV/c)^2, $< W > = 3.0$ GeV, $< W^2 > = 9.7$ GeV^2, and $< \nu > =$ 6.6 GeV.
The selection criteria for the decay of neutral strange particle and the procedure of their identification were similar to those applied in [11]. The number of the accepted V° was 80 out of which 32(48) had the biggest probability to be identified as $K^\circ(\Lambda^\circ)$. The corresponding

average multiplicities, corrected for the decay losses, are $< n_{V^\circ} > = 0.092 \pm 0.010$, $< n_{K^\circ} > = 0.053 \pm 0.009$ and $< n_{\Lambda^\circ} > = 0.039 \pm 0.006$.
For the further analysis the whole event sample was subdivided, using several topological and kinematical criteria [12], into three subsamples: the 'cascade' subsample B_S with a sign of intranuclear secondary interactions, the 'quasiproton' (B_p) and 'quasineutron' (B_n) subsamples for which no sign of secondary interactions was observed. About 40% of subsample B_p is contributed by interactions with free hydrogen. Weighting the 'quasiproton' events with a factor of 0.6, one can compose a 'pure' nuclear subsample: $B_A = B_S + B_n + 0.6B_p$ (with an effective atomic weight $\bar{A} = 28$) and a 'quasinucleon' subsample $B_N = B_n + 0.6B_p$. In the next Section, the characteristics of neutral strange particles in subsamples B_A and B_N will be compared to infer an information about the influence of the nuclear medium on their production.

3 Experimental results

Due to the lack of statistics, we will consider below the combined data on K° and Λ. Table 1 shows the mean multiplicity $< n_{V^\circ} >$ and, for comparison, $< n_{\pi^-} >$ for π^- meson [2], as well as their ratio $R(V^\circ/\pi^-) = < n_{V^\circ} > / < n_{\pi^-} >$ for subsamples B_N and B_A.

Subsample	$< n_{V^\circ} >$	$< n_{\pi^-} >$	$R(V^\circ/\pi^-)$
B_N	0.059±0.012	0.813±0.026	0.072±0.015
B_A	0.096±0.011	0.897±0.020	0.106±0.012

Table 1: The mean multiplicities $< n_{V^\circ} >$ and $< n_{\pi^-} >$ and their ratio for subsamples B_N and B_A.

The quoted value of $< n_{V^\circ} >_N = 0.059 \pm 0.012$ for the 'quasinucleon' subsample is consistent with the data around $W^2 \sim 10$ GeV^2 obtained for neutrino - nucleon interactions (cf. [6] and references therein), while that for nuclear interactions, $< n_{V^\circ} >_A = 0.096 \pm 0.011$, is close to the value 0.102±0.009 measured in [11] for the case of a heavier target (freon), but at somewhat lower $< W^2 > = 7.8$ GeV^2. The relative yields $R_N(V^\circ/\pi^-)$ and $R_A(V^\circ/\pi^-)$ in subsamples B_N and B_A differ by about 1.5 times, i.e. the production of neutral strange particles is influenced by the nuclear medium stronger than that for pions.
The multiplicity gain for π^- mesons, characterized by the ratio $\rho_{\pi^-} =< n_{\pi^-} >_A / < n_{\pi^-} >_N = 1.10 \pm 0.03$, can be qualitatively explained [1] by the secondary intranuclear interactions of produced pions, taking into account the finiteness of their formation lenght [4]. This ratio for V° is equal to $\rho_{V^\circ} = 1.62 \pm 0.23$. (Note, that in the evolution of the error of the ratio $\rho =< n >_A / < n >_N$, the corrrelation between $< n_A >$ and $< n_N >$ was taken into account). If the gain ρ_{V° is caused by intranuclear interactions of produced pions, i.e. by the secondary reactions $\pi N \rightarrow V^\circ + X$, then one can expect that the products of latter will predominantly occupy the backward hemisphere of the hadronic c.m.s., i.e. the region of $x_F < 0$ (x_F being the Feynman variable). This expectation is qualitatively supported by the data presented in Table 2 for two regions of x_F: $x_F > 0$ and $x_F < 0$. The data indicate that the nuclear enhancement of the V° yield occurs mainly in the backward hemisphere.

The ratio ρ_{V° at $x_F < 0$ and $x_F > 0$ is equal, respectively, $\rho_{V^\circ}(x_F < 0) = 1.80 \pm 0.32$ and $\rho_{V^\circ}(x_F > 0) = 1.37 \pm 0.35$. These values differ from those for π^- mesons: $\rho_{\pi^-}(x_F < 0) =$

Subsample	$< n_{V^\circ} >$	$< n_{\pi^-} >$	$R(V^\circ/\pi^-)$
		$x_F > 0$	
B_N	0.025±0.008	0.474±0.019	0.052±0.017
B_A	0.034±0.009	0.437±0.013	0.077±0.021
		$x_F < 0$	
B_N	0.034±0.009	0.339±0.018	0.101±0.027
B_A	0.062±0.010	0.460±0.015	0.134±0.022

Table 2: The mean multiplicities $< n_{V^\circ} >$ and $< n_{\pi^-} >$ and their ratio in regions $x_F > 0$ and $x_F < 0$ for subsamples B_N and B_A.

1.36±0.05 and $\rho_{\pi^-}(x_F > 0) = 0.92\pm0.03$. Unlike V°'s, the π^- yield at $x_F > 0$ is depleted, while the enhancement at $x_F < 0$ is significantly smaller. These depletion and enhancement effects for π^- mesons can be explained by inelastic interactions of produced pions $(\pi^+, \pi^-, \pi^\circ)$ inside the nucleus. The calculations in the framework of a model considered in [1] result in $\rho^{th}_{\pi^-}(x_F < 0) = 1.65\pm0.14$ and $\rho^{th}_{\pi^-}(x_F > 0) = 0.98\pm0.05$, being in a reasonable agreement with the data.

Below an attempt is undertaken to estimate the multiplicity gain, $\delta_{V^\circ}(\pi N) =< n_{V^\circ} >_A - < n_{V^\circ} >_N$, caused by intranuclear interactions of 'primary' pions, $\pi N \rightarrow V^\circ + X$, resulting in production of secondary V° particles. The mean multiplicity of the latter in inelastic πN interactions (averaged over protons and neutrons of the target nuclei), being estimated from the available experimental data [13], increases from $\overline{n}_{V^\circ}(p_\pi) \approx 0.03$ (0.06) for $\pi^+(\pi^-)$ induced reactions at the pion momentum $p_\pi \sim 1$ GeV/c up to 0.15 at $p_\pi \sim 15$ GeV/c (above which the fraction of pions produced in the νN DIS is negligible in this experiment). The probability of the secondary inelastic interactions of pions averaged over their formation length (taken from [4]) and the nuclei of the propane-freon mixture is estimated to be $w_{in}(p_\pi) = 0.24$ at $p_\pi = 1 - 2$ GeV/c decreasing up to $w_{in}(p_\pi) = 0.15$ at $p_\pi \sim 10 - 15$ GeV/c. The integration of the product $w_{in}(p_\pi) \cdot \overline{n}_{V^\circ}(p_\pi)$ over the pion momentum spectrum from $p_\pi = 0.9$ GeV/c to 15 GeV/c results in $\delta_{V^\circ}(\pi^+ N) = (1.5 \pm 0.23) \cdot 10^{-2}$ and $\delta_{V^\circ}(\pi^- N) = (0.50 \pm 0.07) \cdot 10^{-2}$ for π^+ and π^-- induced reactions, respectively, where the quoted errors reflect the uncertainty in $\overline{n}_{V^\circ}(p_\pi)$ [13].
The contribution from π°- induced reactions, $\pi^\circ N \rightarrow V^0 + X$, is assumed to be an average of those for π^+ and π^- mesons, $\delta_{V^\circ}(\pi^\circ N) = 0.5[\delta_{V^\circ}(\pi^+ N) + \delta_{V^\circ}(\pi^- N)]$, with an uncertainty $\pm 0.5[\delta_{V^\circ}(\pi^+ N) + \delta_{V^\circ}(\pi^- N)]$. The resulting expected gain of the V° multiplicity turns out to be $\delta_{V^\circ}(\pi N) = (0.030 \pm 0.007)$ which is in reasonable agreement with the experimental value $\delta^{exp}_{V^\circ} = 0.037 \pm 0.010$ (cf. Table 1).
Note finally, that the applied model of intranuclear interactions is rather crude and uses several simplified assumptions some of which should be pointed out: i) the second-order effects of more than one inelastic collisions of pions are neglected; ii) the charge-exchange reactions like $K^+ n \longleftrightarrow K^\circ p$, $\sum^+ n \longleftrightarrow \Lambda p$ and so on are not considered; iii) the model does not incorporate the production of hadronic resonances with a proper space-time structure of their formation, intranuclear interactions and decay. Hence, more refined model calculations and statistically more provided experimental data are needed to establish whether the nuclear strangeness enhancement observed in this work could be fully attributed to secondary intranuclear interactions or other nuclear effects play a non-negligible role.

4 Summary

For the first time, the influence of the nuclear medium on the neutrinoproduction of neutral strange particles is studied at the energy range $3 < E_\nu < 30$ GeV. The mean multiplicity of V^0 particles in nuclear and 'quasinucleon' interactions are measured. $< n_{V^\circ} >_A$ =0.095±0.011 and $< n_{V^\circ} >_N = 0.059 \pm 0.012$, respectively. The multiplicity gain of V° particles in nuclear interactions, measured as the ratio of $\rho_{V^\circ} =< n_{V^\circ} >_A / < n_{V^\circ} >_N = 1.61 \pm 0.23$, compared to that for π^- mesons, $\rho_{\pi^-} = 1.10 \pm 0.03$, indicates that the nuclear influence on the strange particle production is larger than for non-strange one.
The measured value of the difference $\delta^{exp}_{V^\circ} =< n_{V^\circ} >_A - < n_{V^\circ} >_N = 0.037 \pm 0.010$ is mainly contributed by the multiplicity gain in the backward hemisphere ($x_F < 0$) and can be approximately described by a simple model incorporating the secondary inelastic interactions of produced pions within the nucleus.

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